MINOR MINERALS IN THE JEZERO CRATER DELTA ANALYZED BY PIXL – PROVENANCE & MARS SAMPLE RETURN IMPLICATIONS.

T. V. Kizovski[1], L. O'Neil[2], M. Schmidt[1], J. Hurowitz[3], A. Treiman[4], D. Pedersen[5], Y. Liu[6], M. Tice[2], C. Herd[7], J. Labrie[1], J. Christian[8], A. Knight[8], S. VanBommel[8], E. Moreland[9], E. N. Mansbach[10], J. Simon[11], and A. Allwood[6]. [1]Brock U. (St. Catharines, ON L2S 3A1 Canada, tkizovski@brocku.ca), [2]Texas A&M (College Station, TX 77843), [3]SUNY Stony Brook (NY 11794), [4] Lunar Planet. Inst. / USRA (Houston, TX 77058), [5]DTU Space, Tech Univ. of Denmark (Kongens Lyngby, Denmark), [6]JPL-Caltech (Pasadena, CA 91125), [7]U. Alberta (Edmonton, AB T6G 2E3 Canada), [8]Wash.U (St. Louis, MO 63130), [9]Rice U. (Houston, TX 77005), [10]M.I.T. (Boston, USA), [11]NASA JSC (Houston, TX 77058).

Introduction: On February 18, 2021 the Mars 2020 Rover *Perseverance* landed on the floor of Jezero crater, an ancient, ~45 km diameter impact crater that once contained a lake [1]. Since landing, the rover has traversed ~14 km across the crater's floor and western delta, analyzing various outcrops in order to piece together the area's geologic history, and collect samples for eventual return to Earth.

The Planetary Instrument for X-ray Lithochemistry (PIXL; an X-ray fluorescence [XRF] spectrometer on-board the rover) is crucial for this purpose, producing high-resolution (~120 μm spot size) elemental abundance maps on rock targets of interest [2]. Due to the high-resolution of these scans, they can be used to identify minor, smaller-sized phases of interest (such as phosphates, oxides, and Zr-bearing minerals) in-situ. The composition and occurrence of these phases can provide insight into the geologic history of Jezero crater [i.e., 3], and help discriminate between organic and mineral signatures detected by SHERLOC [4]. The minor phases also have immense value in return samples as geochronometers (phosphates, Zr-phases [5,6]), and recorders of paleomagnetic signatures (oxides, Zr-phases [7]), magmatic evolution (all), and sedimentary processes (all). As such, here we summarize the results of PIXL analyses of minor mineral phases encountered in the western delta of Jezero crater. Through careful examination of their chemistry and textures, as well as comparison with minor mineral assemblages identified in igneous rocks on the crater floor [8], new insights into the geologic history of the delta can be revealed.

Method: XRF mapping by PIXL was carried out on 8 outcrops in the delta. This includes 7 natural surface scans, and 8 scans collected within 50 mm circular abrasions (which provide a relatively smooth, dust-free surface beneath coatings). Abraded rock targets are considered here; natural surfaces and regolith targets will be included in future work. The XRF maps range in size from 35-50 mm^2, with a step size of ~0.125 mm. Minor minerals are typically smaller than this, so they are detected as mixtures with other minerals. The compositions of the various phosphate and oxide phases were constrained from the mixing trends with silicate minerals and Ca:P, and Fe:Ti:Cr ratios (respectively). Zirconium-phases were inferred for spots where high concentrations of Zr were observed. All element concentrations were corrected for surface roughness and X-ray diffraction [9].

Results & Discussion: The PIXL map scans show that the compositions and occurrences of minor phases vary across the delta (see [10] for a more detailed overview of the stratigraphic units).

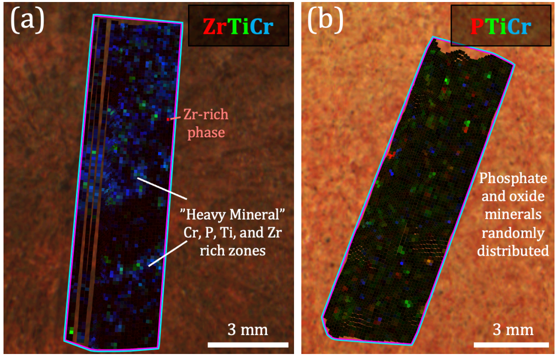

Figure 1: (a) RGB X-ray element map where Zr, Ti, and Cr are concentrated in layers within the Novarupta abrasion (Amalik member). (b) RGB X-ray element map showing P, Ti, and Cr in the Berry Hollow abrasion (Hogwallow Flats member), and the random distribution of oxide and phosphate minerals in this rock.

Sandstone of the Amalik member (Novarupta Abrasion):

Ca:P ratios and mixing trends with silicates show that the phosphate minerals examined in the Novarupta abrasion likely include both apatite and merrillite. The Cr-Ti-Fe-oxide minerals are predominantly Cr-rich, with significant variation in Cr:Ti. One Zr-rich spot (Zr = ~1.4 wt%; Fig. 1) was identified – potentially baddeleyite or zircon, although with available data, we cannot say which mineral contains the elevated Zr. Notably, the phosphate minerals, oxides, and Zr-phases are all concentrated in lamellar bands across the abrasion surface, suggesting that these grains represent a heavy mineral lag that likely formed by differential entrainment of small, dense grains and larger less dense grains.

Bedded sandstone of the Lower Rockytop member (Thorton Gap Abrasion):

The phosphates minerals exposed in the Thorton Gap abrasion likely include both apatite and merrillite.

Similarly to the Novarupta abrasion, the Cr-Ti-Fe-oxide minerals in Thorton Gap show a range of Cr:Ti ratios, and are predominantly Cr-rich. The phosphate and oxide minerals are randomly distributed within the fine-grained matrix of this clast-rich sandstone.

S-rich Siltstone of the Hogwallow Flats member (Berry Hollow Abrasion):

The phosphates exposed in the Berry Hollow abrasion likely include both apatite and merrillite, and a potential secondary phosphate phase with Ca:P (molar) ~1 (which is also observed in the highly evolved basalts of the Máaz formation on the crater floor [8]). Cr-Ti-Fe-oxide minerals in Berry Hollow show a bimodal distribution of Cr:Ti ratios (i.e., either very Ti-rich oxides, or very Cr-rich oxides, with few Cr/Ti-rich oxides; Figure 2). The phosphate and oxide minerals are randomly distributed throughout the siltstone (Fig. 1).

S-rich Siltstone of the Yori Pass member (Uganik Island Abrasion):

The phosphates exposed in the Uganik Island abrasion likely include both apatite and merrillite. Cr-Ti-Fe-oxide minerals in Uganik Island again show a bimodal distribution of Cr:Ti ratios, similar to that in Berry Hollow. The phosphate and Fe-Ti-rich oxide minerals are randomly distributed throughout the siltstone; however, the Cr-rich oxides are only observed in one of the two PIXL scans completed on this target. The reason for this heterogeneity is unknown at this time.

Comparisons to the Crater Floor:

Figure 2 summarizes the oxide mixing trends observed by PIXL in the rocks of the Jezero delta and compares them to the trends identified in the crater floor (Máaz and Séitah formations [8]). The goal is to determine if either of these formations, or rocks similar to these formations, could be among the sources for the delta sediments. We focus on the oxide minerals in this discussion as phosphate mineral compositions did not vary significantly across the analyzed delta sediments.

Crater Floor Oxide Minerals:

In the highly evolved basalts of the Máaz formation, the Fe-Ti-Cr oxides are typically Ti-rich, with rare occurrences of Cr-rich oxides also observed (bimodal distribution of Cr:Ti ratios). The Fe-Ti-Cr oxides in the olivine cumulate rocks of the Séitah formation are relatively Cr-rich, and show more variation in Cr:Ti.

Delta Oxide Minerals:

As shown in Figure 2, the Ti-rich oxides observed in the Uganik Island and Berry Hollow abrasions are both relatively "Máaz-like". However, the Fe-Ti-Cr oxide minerals in Berry Hollow and Uganik Island also contain a significant portion of Cr-rich oxides (a rare occurrence in Máaz formation rocks analyzed by PIXL). The Si-Cr-Ti mixing trends observed in Uganik Island and Berry Hollow are also very similar suggesting they may be from the same stratigraphic member. This is perhaps unsurprising as they are both S-rich siltstones.

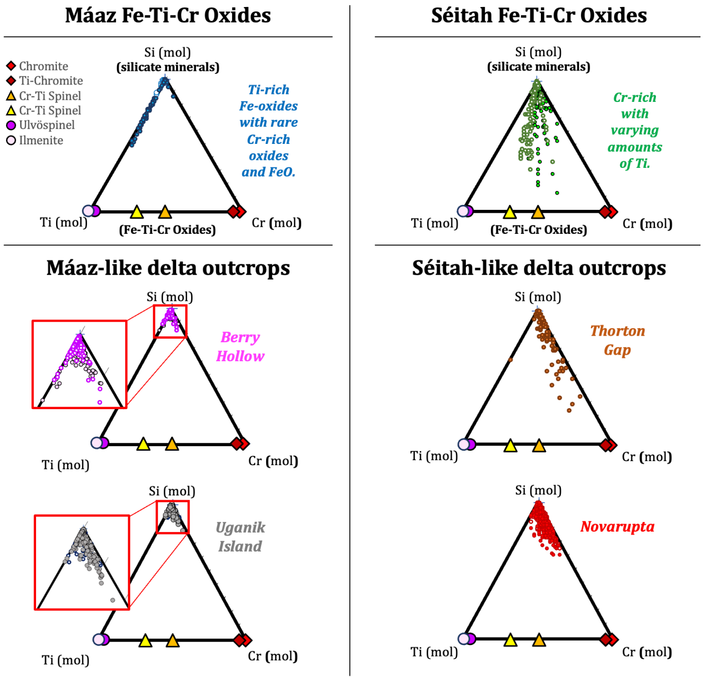

Figure 2: Si, Ti, and Cr ternaries showing the mixing trends between the silicate minerals and Fe-Ti-Cr oxides in the crater floor (Máaz and Séitah [8]), and the delta rocks examined by PIXL. Each point corresponds to an XRF PIXL point. The column each sample is placed in indicates which crater floor unit it is most similar to based on oxide mixing trends, although differences are still evident (See text for more details). Ideal Cr-Ti-Fe oxide compositions along the bottom of the ternaries are from olivine-phyric shergottite Tissint [11], which contains a wide variety of Cr-Ti-Fe oxides.

The oxide minerals observed in the Thorton Gap and Novarupta abrasions have more variable Cr:Ti compositions, similar to what is observed in Séitah. However, in both Thorton Gap and Novarupta, the Cr-rich oxides are the more dominant phase, with few Ti-rich oxides relative to Séitah.

The increased proportion of Cr-rich oxides observed in the delta targets' mixing trends when compared to both Séitah and Máaz could indicate different (possibly more mafic) source regions all together for these sedimentary outcrops; grain size differences between Cr and Ti-rich oxides; or enrichment of Cr and loss of Ti through transport, deposition, and/or alteration. Future work will address these possibilities.

References: [1] Farley K. A. et al. (2020) *Space Sci. Rev. 216:142*. [2] Allwood, A. C. et al. (2020) *Space Sci. Rev.* 216: 314. [3] Liu Y. et al., (2022) *Science*. 377:6614 [4] Scheller. E. et al (2023) LPSC LIV. [5] Chew and Spikings (2015) *Elements*. 11:189-194. [6] Moser et al. (2013) Nature. 449:454-457 [7] Mansbach. E. et al (2023) *LPSC LIV* [8] Kizovski et al. (2022) *AGU*. [9] Tice et al (2023) *LPSC LIV*. [10] Hurowitz et al. (2023) *LPSC LIV*. [11] Gattacceca et al. (2013) *MAPS. 48:10.*